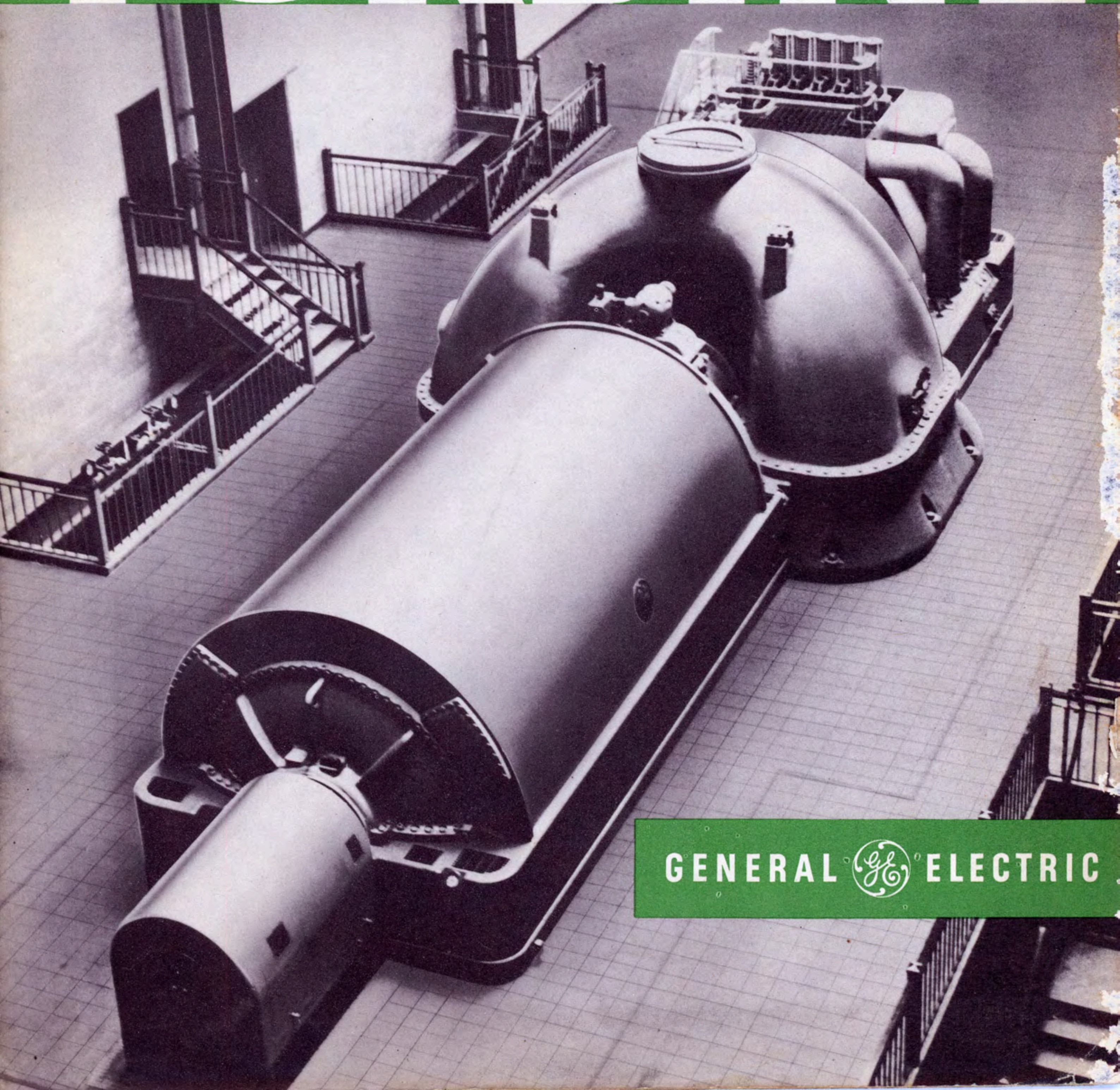
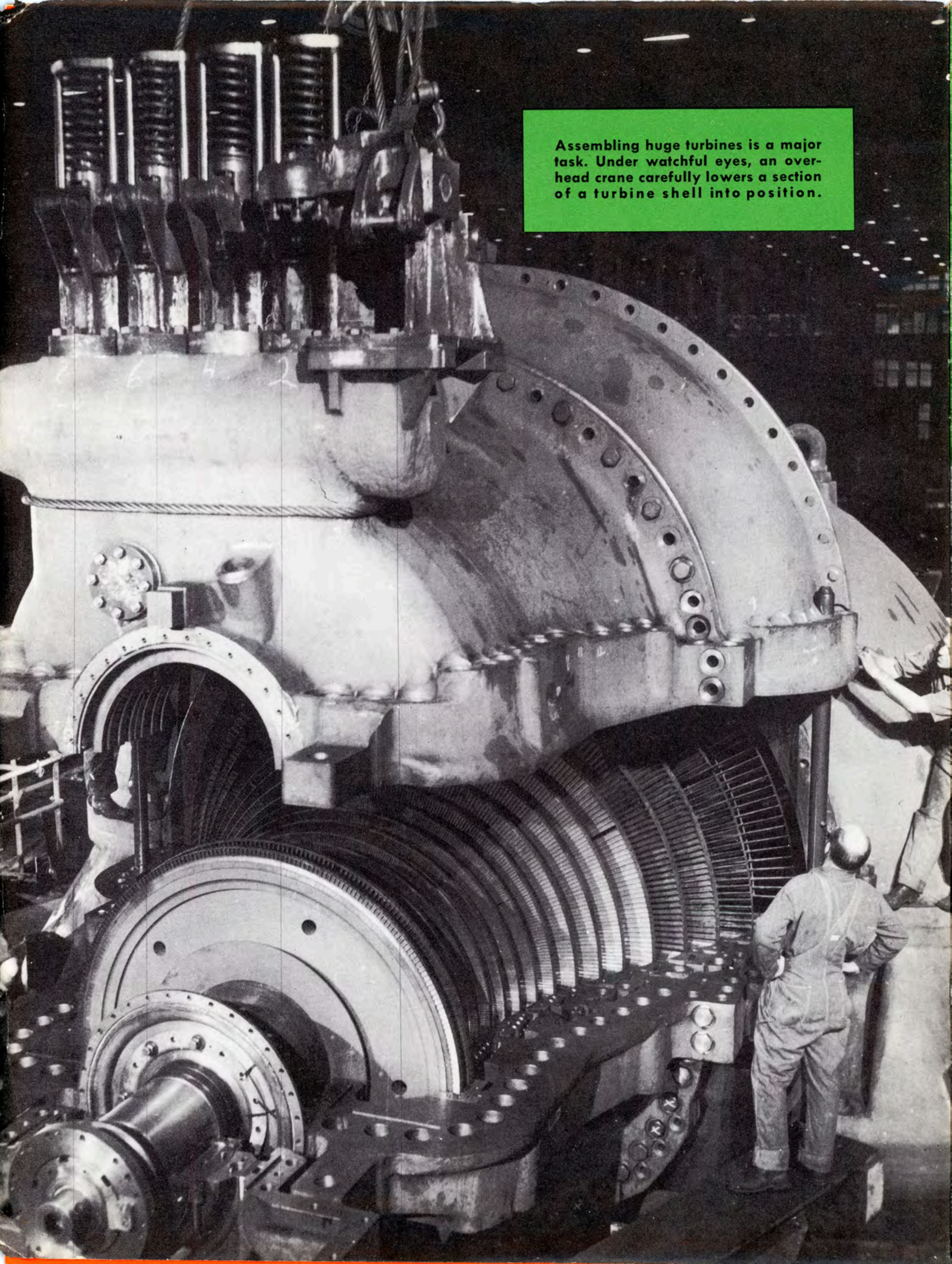
APD-68

Story of the TURBINE



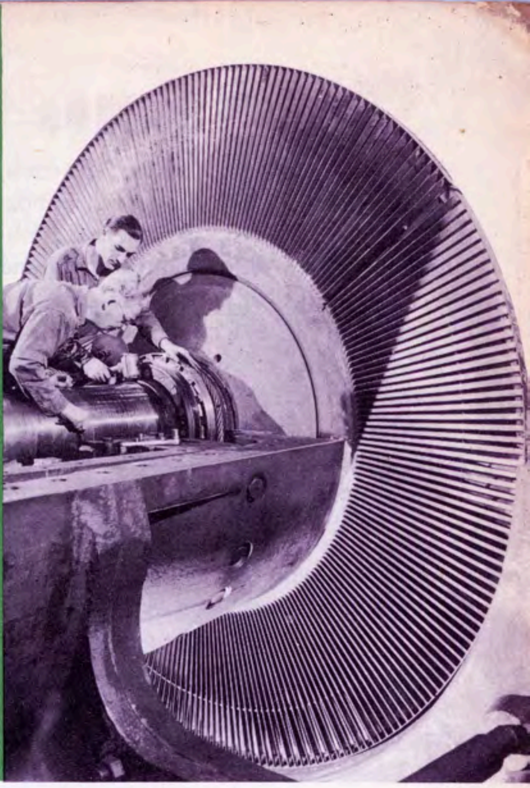
GENERAL ELECTRIC



Assembling huge turbines is a major task. Under watchful eyes, an overhead crane carefully lowers a section of a turbine shell into position.

Story of the TURBINE

Here is the story of the quiet-spinning, tireless turbines which drive mighty generators to produce most of our nation's electric power



Bucket wheels at the low-pressure end of the turbine are frequently 12 feet in diameter on the large turbines.

EVERY BOY OR GIRL who has ever built a windmill has discovered for himself the ancient principle of the turbine. A steam turbine is a series of windmill vanes, called buckets, set in wheels mounted on a shaft in such a way that steam—in lieu of wind—can be directed against these buckets to cause rotation of this shaft.

In this type of windmill the vanes are high-grade alloy steel, the wind—i.e. high-pressure, high-temperature steam—blows at 1200 miles an hour, and the wheels turn at 600 miles an hour.

It is hard to grasp the magnitude of the forces at work inside the turbine shell. A hundred-mile-an-hour wind is a tropical hurricane. It will devastate entire communities. But the blast that blows upon the curved blades that are a turbine's buckets has twelve times the velocity of the hurricane!

Why such high pressures? A fall in steam pressure exerts a force in much the same way as falling water. In a waterwheel, the power depends on two things: the quantity of water that flows through the wheel and the distance the water falls. So if one dam is built twice as high as another on the same stream, twice the power will be generated.

The steam pressure used in modern steam turbines is 1200-2000 pounds per square inch. Just as remarkable, the steam, after entering the turbine, emerges 1/30th of a second later—in a vacuum. The steam pressure in the last stages of the turbine is actually less than that of the air outside, for the condenser converts the rapidly cooling steam to water and in so doing creates a vacuum. The steam darts through approximately 20 feet of buckets and nozzles in a split second. In this 20 feet, it passes through from 17 to 20 turbine wheels, an equal number of nozzles, and pushes against some 5000 buckets. No wonder we speak of the emerging steam as being "exhausted."

But why go 20 feet to exhaust the steam? This is done to improve efficiency and consume less fuel. In this more efficient arrangement, the steam expends its energy gradually by passing through successive sets—called stages—of stationary nozzles and revolving buckets. The steam, expanding from the nozzle, strikes a row of buckets on one wheel, loses some of its velocity and pressure, passes into another set of nozzles, through another row of buckets, and so on down the line. At the high-pressure end—where the steam enters the turbine—the buckets are small. This is because the density of the steam is so great that it has to make contact with only a very small surface in order to move it. As the steam progresses through the turbine, it loses density at each stage. Conversely, the buckets become larger toward the opposite end—the low-pressure end. Sometimes the wheel that holds the last set of buckets is 12 feet in diameter.

Faster Than Sound

The turbine is definitely a high-speed machine. Traveling faster than the speed of sound, each of the larger turbine buckets exerts a centrifugal force of 90,000 pounds. But, if speed and pressure, enormous as they are, were the only problems, the job of the turbine engineer would be relatively simple. Complicating his job is the inseparable companion of high steam pressure—high temperature. Therefore, special metals, appropriate for high temperatures, are used in turbine construction. One thousand degrees is the temperature of steel when it glows dull red. That is to say that the high-pressure buckets of the turbine run red hot—while a few feet away the large low-pressure buckets are running through a tepid rainstorm! The turbine is going so fast that this rain—actually drops of condensed steam—would cut like a sandblast if it were not for the specially designed metals used to resist this action.

Scientists and engineers worked for many years to design and develop the materials necessary to withstand such an onslaught. They made thousands of measurements and tests. Years ago, General Electric engineers had a brilliant idea—a wind tunnel for turbines.

Jets of compressed air, instead of steam, were passed through the turbine's nozzles and buckets. By this means, thousands of observations were quickly and easily recorded on automatic precision instruments in much the same manner as the smooth, gleaming surface designs of modern streamlined airplanes are tested in wind tunnels. However, there is one big difference—a turbine's streamlining is on the *inside*.

Other tests have been made over a period of many years. The effects of high temperatures upon various metals are under constant scrutiny. For more than 20 years, General Electric testing laboratories have been "cooking" an endless number of steel alloys—some for months, some for years. Their stresses and "creep"—or permanent expansion under high temperatures—are being carefully recorded.

With high temperatures, high pressures, and high speeds, you might think that the engineer had been confronted with all the major problems possible. But there was still another—vibration. Vibration had cracked buckets and wheels and completely wrecked entire turbines, even after years of operation. The basic solution of this problem is only another achievement of General Electric engineering and research. Considering these difficulties, it is understandable that it took scientists and engineers many years to produce the turbine as it exists today.

How Old Is the Turbine?

There are those who say the principle of the turbine is old. Probably just as many think it is a relatively new development. Actually, there is justification for both of these concepts.

In 120 B.C., the Roman Empire was busy pursuing its policy of conquering Greece and Egypt. At the same time, a learned Egyptian writer, Hero, was making the first application of the steam turbine.

He displayed his idea in a gadget called an Eolypyle. The toy worked on the same principle as the modern automatic lawn sprinkler, yet it didn't perform any useful function other than to demonstrate the expansive power of steam and its ability to do work.

Nearly 2000 years passed before any thought was given to the actual utilization of steam power. It wasn't until 1629 that an Italian scientist, Giovanni de Branca, proposed the use of a jet of steam to produce rotation. But his steam wheel was unsuccessful, because man had not yet mastered mechanical construction.

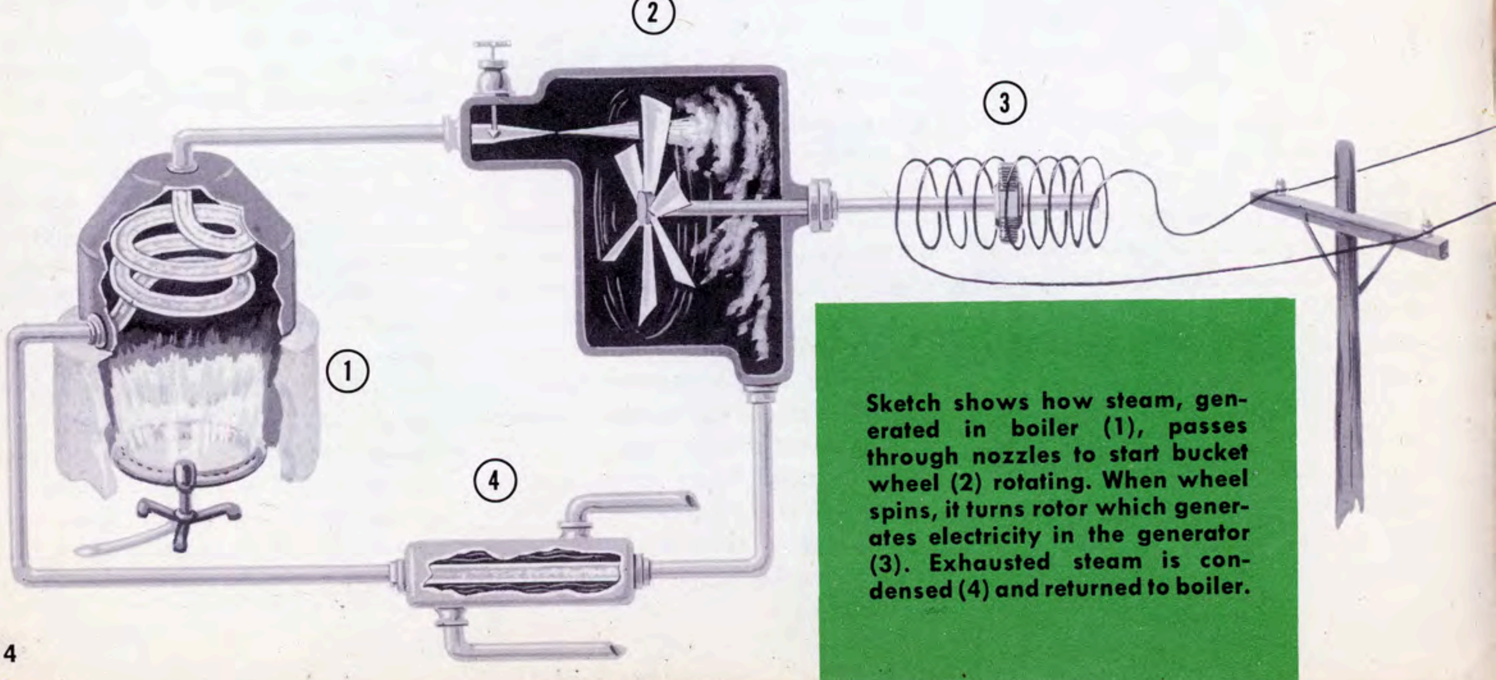
Late in the 18th century, James Watt, builder of one of the first practical steam engines, believed he had solved most of the construction problems. He boasted that one of his large steam cylinders was "only three-eighths of an inch out of round!" Here is an interesting comparison in that General Electric today machines its turbine parts to 1/1000th of an inch!

Enter Charles G. Curtis

In 1884, Sir Charles A. Parsons developed the first practical reaction turbine. Twelve years later, a young American, Charles G. Curtis, contributed something new. He patented the impulse-type turbine.

The first Curtis turbines built were the talk of the power industry. Reliable and economical to manufacture, these turbines incorporated one of many interpretations of the Curtis stage. Each of the several stages in the turbine consisted of a nozzle diaphragm and two rotating sets of buckets separated by one stationary set. The nozzles directed high-velocity steam against the first set of movable buckets to start the bucket wheels rotating. Because of the curvature of each bucket, the steam emerged on the other side of the first wheel traveling in the opposite direction from that at which it entered. The stationary set of buckets curved the flow back into its original direction and into the second set of movable buckets, thereby completing the first stage. The steam continued on into the second nozzle diaphragm and the same thing that took place in the first stage occurred in this second stage and every stage thereafter.

Later, another version of the Curtis stage was found to be even more efficient. Instead of using two sets of movable buckets in each stage, only one was used. This automatically eliminated the stationary set of buckets



Sketch shows how steam, generated in boiler (1), passes through nozzles to start bucket wheel (2) rotating. When wheel spins, it turns rotor which generates electricity in the generator (3). Exhausted steam is condensed (4) and returned to boiler.

The United Illuminating Company's power station at New Haven, Conn., uses G-E turbine-generators to help keep it ahead of the increasing demand for electric power.

at the same time. Therefore, the later representation of the Curtis stage was comprised of merely a nozzle diaphragm and one set of movable buckets. It is this design that is used in today's General Electric turbines.

Teamwork Does the Trick

Although Curtis possessed the patent, he was faced with the problem of manufacturing his turbine. He didn't have the facilities for building such a massive machine—nor did he have the money for such an undertaking.

It was not long before Curtis sought the co-operation of the General Electric Company. And, in 1897, General Electric and Charles Curtis developed a turbine that achieved wide acceptance in the steam turbine industry.

The first Curtis-type steam turbine was built in General Electric's home plant—Schenectady, N. Y. But at first it didn't work. It was at this point that a young General Electric engineer, W. L. R. Emmet, played a very important role in this development period. Emmet undertook the task of redesigning the turbine. In November of 1901, the Curtis-Emmet turbine was successfully operated. It was rated at 500 kilowatts at a speed of 1200 revolutions per minute. Early in 1902, this turbine began regular service in the General Electric shop plant at Schenectady, driving an alternating-current generator.

The first General Electric steam turbine to be placed in commercial service was rated 500 kilowatts at 1800 revolutions per minute. It was shipped from Schenectady in 1903, to the Newport and Fall River Company, Newport, Rhode Island. A month later, a 5000-kilowatt turbine was installed at the Fisk Street Station of the Commonwealth Electric Company in Chicago. At the time, it was the largest turbine-generator ever built. Its evolution is a story in itself.

The Undaunted Madigan

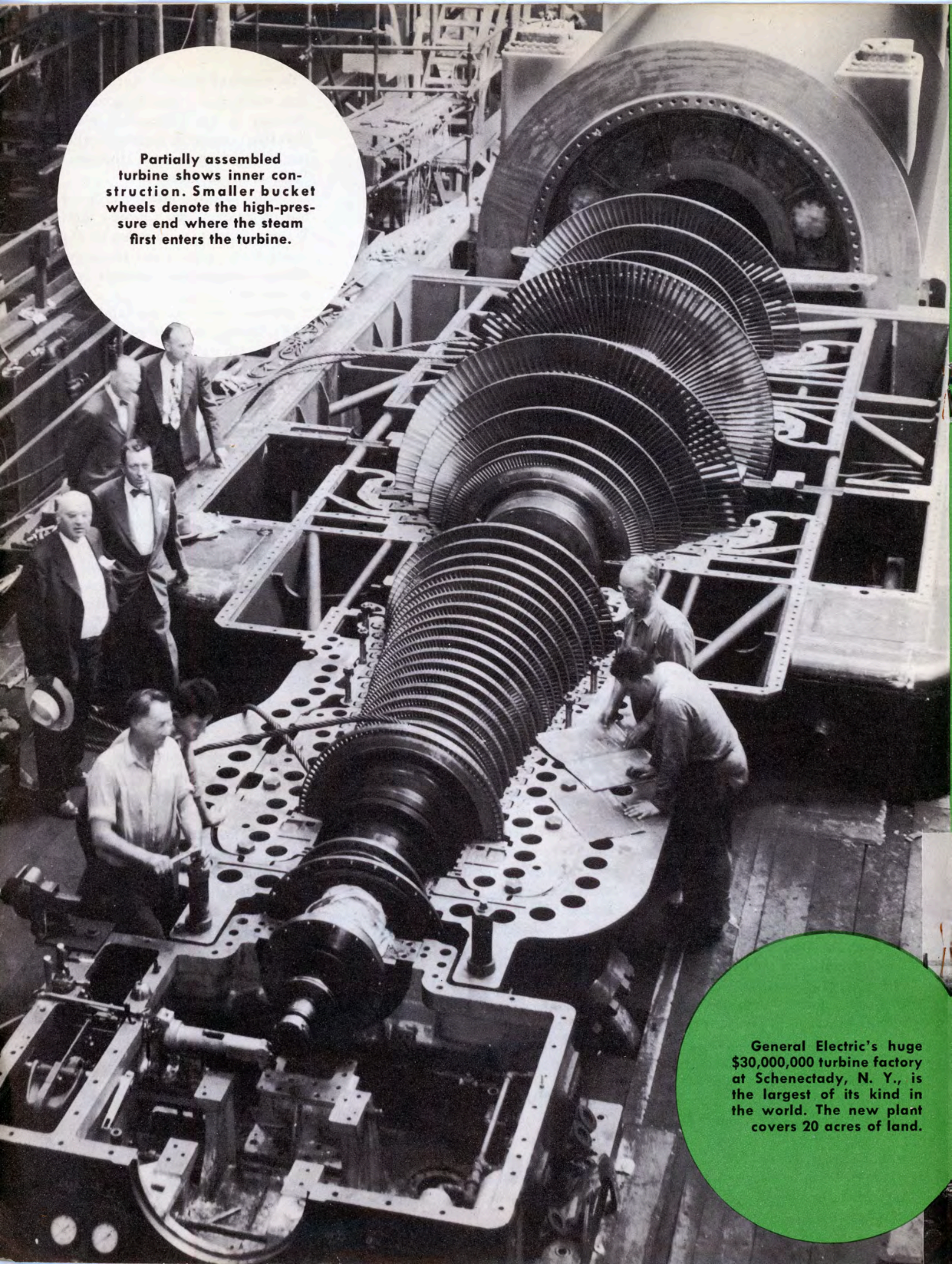
Early in 1903, the Chicago turbine was far from ready. Chicago began to ask when the first factory test of the big turbine would be made. General Electric, its reputation at stake, said "the month of March." Automatically, this signaled for drastic action. The manager of the Schenectady plant at that time, George E. Emmons, called in one of his young foremen. His name was William M. Madigan.

"Bill," said the manager, "we're in hot water over that Chicago turbine. We've *got* to get steam in her by March —and we've picked you to swing it. Think it over and let me know as soon as possible."

Madigan didn't have to think it over. The following Monday he began to lay out his plan as if he were mapping a military offensive. He gathered his men and gave them their assignments. From then on, there was no let-up. To keep the project going, Bill himself stepped in and worked with his own hands. He was so confident in his and his workers' ability that he even predicted that March 7th would be the big day—the day they would turn on the steam. However, his workers and engineers were not quite so confident. "Bill must be crazy," they were saying.

March 1st arrived and it looked as if the latter might be right. They had already made phenomenal progress, but there was still much more to do. March 2nd—engineers, designers, machinists and Billy Madigan were working around the clock. The manager and vice presidents were on pins and needles. March 3rd rolled by. Tension mounted by the hour. Then—on March 4th, a grimy, dirty, dog-tired Madigan wearily said, "Let in the steam, boys." Three months later the big turbine was running steadily, day and night, producing electric power for the Commonwealth Electric Company in Chicago. It required only one tenth the space and weighed one eighth as much as the reciprocating engines it replaced. The cost? One third!

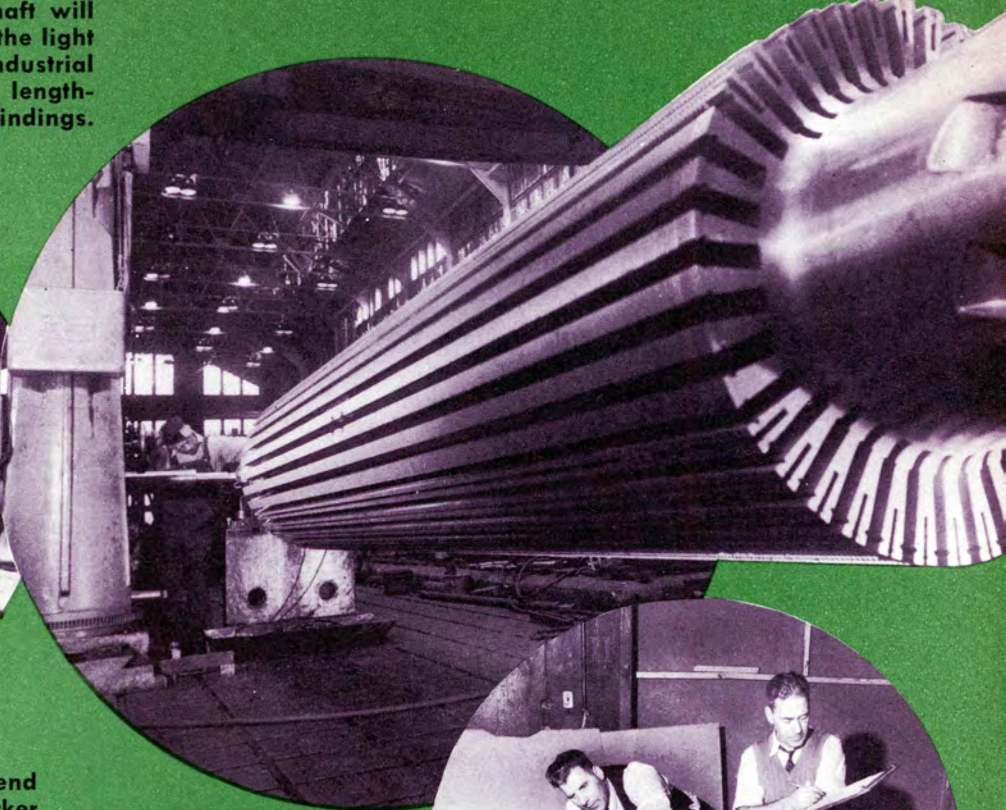
Billy Madigan was one of the first of General Electric's turbine foreman. Stories of such men are almost forgotten, and yet these men are now found in any General Electric plant by the hundreds, contributing a vital part to the building of great steam turbines. Generally recruited from the ranks, they definitely belong in any story of G-E turbine production—or in any other story of American industrial achievement.



Partially assembled turbine shows inner construction. Smaller bucket wheels denote the high-pressure end where the steam first enters the turbine.

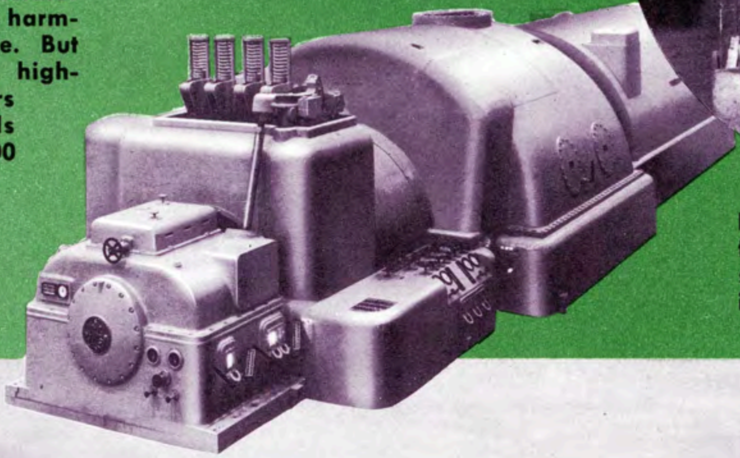
General Electric's huge $30,000,000 turbine factory at Schenectady, N. Y., is the largest of its kind in the world. The new plant covers 20 acres of land.

This giant turbine-generator rotor shaft will play an important part in supplying the light and power needs of domestic and industrial consumers in a good size city. The length-wise slots will accommodate the windings.

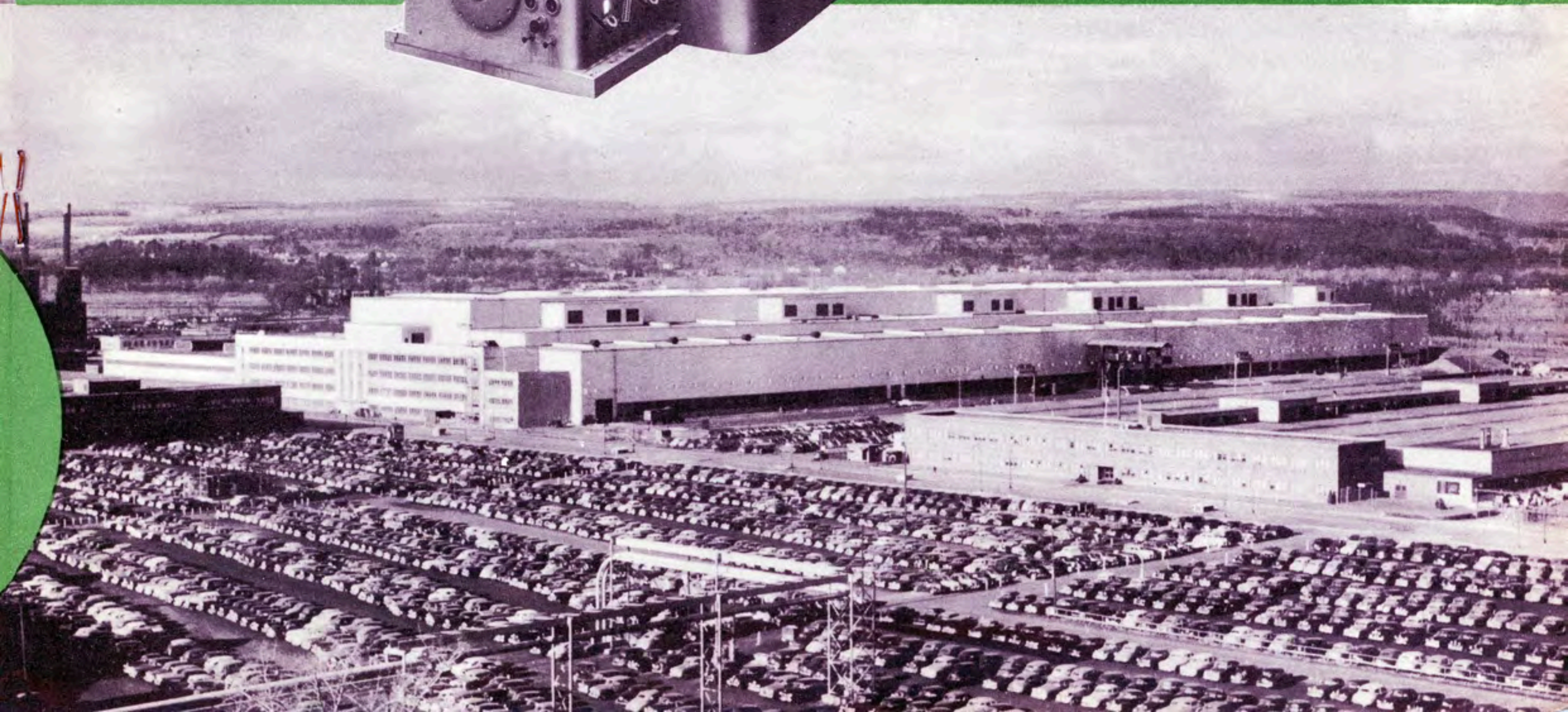


Textolite blocks are used to hold the end turns of the coils securely in place. Worker is shown positioning blocks for insertion.

The steam turbine-generator looks and sounds quite harmless from the outside. But within its sleek shell, high-velocity steam thunders into the bucket wheels at a speed of about 1200 miles an hour.



Nozzle diaphragm section is carefully inspected to be sure it meets design requirements. The diaphragm is constructed in two sections.



USS *Newport News* is of the Salem class and one of the most powerful heavy cruisers afloat. It is equipped with G-E propulsion turbines.

A Demand Is Born

The superiority of these turbines was so marked that General Electric was kept busy trying to fill the increasing demand. Within three years, a world-wide market had been established for Curtis-type turbines. Steam turbines had been built and shipped to England, Ireland, Germany, France, Japan, South Africa, New Zealand, Siam, and Canada. Orders for more were pouring into the offices of the General Electric Company.

But there were some men who were still not satisfied. After Curtis and Emmet, an engineer named Oscar Junggren obtained over 100 patents on turbine features. With painstaking, scientific thoroughness, these men, and the G-E engineers who followed them —E. D. Dickinson, M. A. Savage, A. R. Smith, G. B. Warren, and many others —embarked upon an almost infinite series of turbine improvements.

The Turbine Goes to Sea

By 1909, the steam turbine had pretty well established itself on land. Emmet, the G-E engineer who had helped Curtis perfect his original turbine, began looking around for new fields to conquer. Not a man for mediocrity, he picked—the battleship. It was a logical choice due to its size and power requirements, but there was one big problem involved. Emmet would have to sell the idea of the turbine's superiority before he could demonstrate it.

Evidently, Uncle Sam's Navy was hard to convince, for the first trial run of turbine-electric drive in a naval vessel was made—not on a mighty battlewagon—but on a humble collier, the *Jupiter**. However, the Navy did join with General Electric engineers in eagerly observing these trial runs. The tests illustrated the simple operation of turbine-electric propulsion as well as its efficiency. Top Navy officers were satisfied that the turbine was a complete success in the case of the *Jupiter*. But a battleship! It couldn't be done! The weight of the machinery would sink the ship!

Emmet maintained that the steam turbine would supersede the steam engine. His persistence was rewarded in 1917 when the powerful 32,000-ton battleship, *New Mexico*, was commissioned. Powered by two General Electric steam turbine-generators, she required only nine boilers—as compared to the twelve boilers necessary on other battleships of this class. Her dozen oil tanks were capable of carrying 1,000,000 gallons of fuel. This was the beginning of large-scale mobile use of the steam turbine.

For Commerce on the Seas

On October 1, 1927, the huge 30,250-ton SS *California* was launched. This was the first installation of turbine-electric propulsion for a large commercial vessel. Here, two General Electric steam turbine-generators made it possible for her to save two full days on the 5500-mile run between California and New York.

The luxurious turbine-electric ship had become front-page news. The SS *Virginia*, duplicating in most details the construction of the *California*, was publicized as the world's largest electrically driven ship. She was 613 feet long and carried 801 passengers.

The turbine continued to write its story of power and speed. In 1928, the Navy's proud aircraft carrier, the 33,000-ton USS *Saratoga*, achieved a speed of 34.99 knots—nearly 40 miles an hour! Known as the "Sara" by World War II veterans, the mighty carrier wound up her glorious career still performing as a guinea pig for science. In "Operation Crossroads"—the Bikini atom bomb test in mid-1946—"Sara" slipped beneath the surface of Bikini Lagoon. In a matter of seconds, the atom bomb had done what the enemy had unsuccessfully attempted to do in 44 months of the fiercest naval warfare in history.

But not all the turbine-electric ships were so large. In 1929, General Electric was the first to apply the steam turbine-generator to a car ferry operating on the Great Lakes. It ferried 30 modern freight cars across the deep waters at 20 miles an hour. The same year, General Electric contracted to build propulsion equipment for the Grace Steamship

The 23,500-ton President Cleveland's twin G-E turbine generators power the two propulsion motors which provide 18,000 horsepower, and drive the great ship at a speed of 19 knots.

**It was the Jupiter that the Navy later converted into the first American aircraft carrier—the USS Langley.*

Lines and the Ward Line. After two years' study with G-E engineers, the Dollar Line settled upon plans for building 600-foot, twin-screw, 20-knot liners.

For Mighty Conflict

In 1933, Franklin Delano Roosevelt took office for his first term in the White House. Adolph Hitler had begun to carry out his *Mein Kampf* preachings. At the same time, our Navy was in the process of modernizing its fleet. Four destroyers were under construction and were to be powered by General Electric turbines. But putting turbines in the slender hulls of destroyers was not easy. A. R. Smith and G. B. Warren played major roles in solving this space problem. By building a 400-pound, high-speed, high-temperature propulsion turbine, they reduced the number of buckets necessary by 75 per cent, reduced the length of the rotor 25 per cent, and increased the horsepower by 10,000!

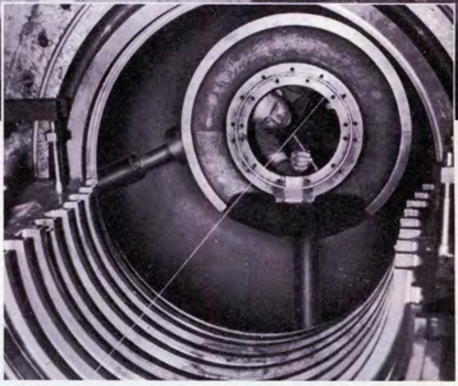
The first of this class of ships, the USS *Mahan*, was delivered in 1936. She was equipped with high-speed turbines and double reduction gears—another General Electric development—improved boiler feed systems, and a cruising turbine.

These ships were followed in rapid succession by other modern destroyers incorporating the same fundamental design features—but using even higher temperatures and pressures. One of these vessels, the USS *Somers*, was the first ever equipped with air-encased, separately controlled superheat boilers and turbines.

As a result of the *Somers*' success, all battleships, cruisers, carriers, and large destroyers of World War II were equipped with high-pressure, high-temperature turbines and the double "locked train" type of reduction gear developed under the direction of two General Electric engineers, A. A. Ross and E. N. Twogood. A unique design feature, the "locked train" principle enables the main gear to transmit much more power than the gear of prewar design.

During World War II, the Navy had 483 ships powered by General Electric turbines. Of these, 347 were turbine-gear drive totaling 23,149,000 horsepower; 136 were turbine-electric drive totaling 1,632,000 hp. In addition, 848 Merchant Marine ships were propelled by General Electric turbines. Of these, 471 were turbine-gear drive totaling 3,242,500 hp; 377 were turbine-electric drive totaling 2,558,000 hp.

A huge generator armature is readied for shipment. Two powerful cranes were required to lift this 194-ton giant and lower it gently into position.



With the aid of micrometer stick and wire running through the machine's center, a workman checks alignment of turbine's exhaust hood housing.

Many of the G-E propelled ships, built for wartime use, have been modified for peacetime cargo and passenger service. One of these, the SS *Santa Rosa*, traveled more than 1,120,000 nautical miles during its four years as an Army transport. She required no repairs during 38 intercoastal trips via the Panama Canal, 86 round trips in Caribbean service from New York, and 27 round trips to the three war areas from East Coast ports.

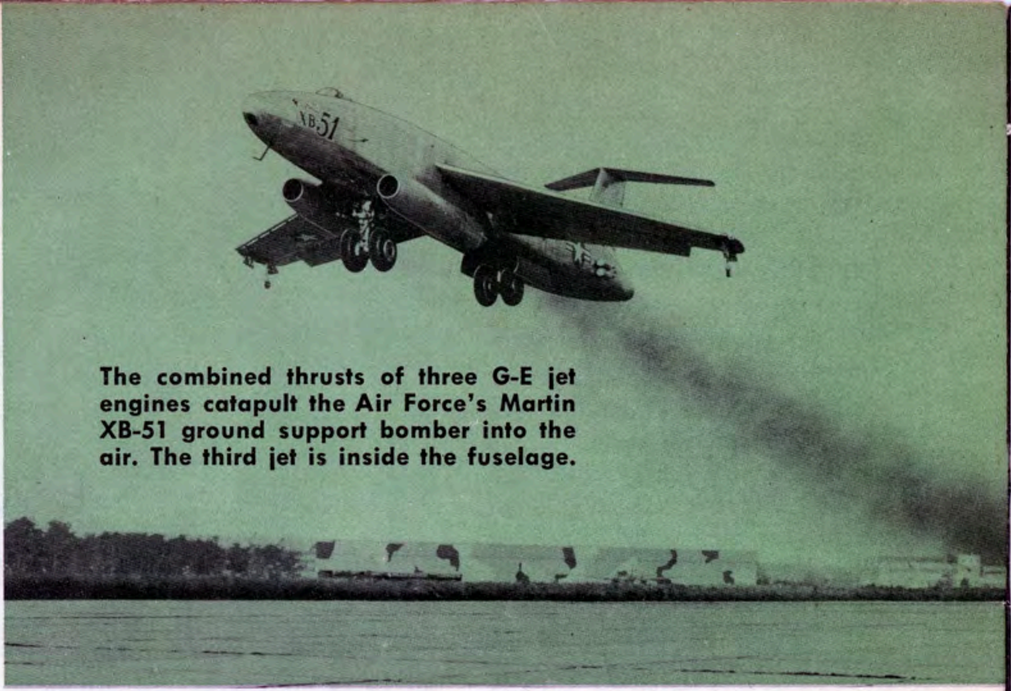
To Ease the Load

Today, the average American home has become a household of time- and labor-saving devices. There are electric irons, toasters, vacuum cleaners, electric mixers, radio and television sets, clocks, and all sorts of electric lamps, from Christmas tree lights to ultraviolet sunlamps. No one will deny that these electrical conveniences have lightened mankind's burdens. They have brought enjoyment to everyone. But we wouldn't be able to use all of these servants so readily if it wasn't for the low cost of electric current.

And reduction in the cost of electricity has been due in many ways to the continually improved efficiency of the steam turbine. In the last 70 years the cost of electricity has decreased 86 per cent. Since 1940, it has decreased approximately 13 per cent.

Some interesting facts also turn up if we consider that a modern turbine-generator set of 150,000-kilowatt capacity is large enough to produce electricity for domestic and industrial users in a city of 450,000 such as Columbus, Ohio. To provide steam for such a turbine, enough coal to heat annually 75,000 average sized homes—some 600,000 tons—is needed each year. To burn this coal, more than 500,000 cubic feet of air will be required each minute.

Converting the turbine's exhaust steam back into water requires 93,000 gallons of cool water per minute to be circulated through the condensing unit. This is about seven and a half times what a city like Schenectady, New York, with 90,000 population, would require in one minute.



The combined thrusts of three G-E jet engines catapult the Air Force's Martin XB-51 ground support bomber into the air. The third jet is inside the fuselage.

Fuel from the Atom?

Many questions arise concerning tomorrow's power. Scientists can conceive of nuclear energy supplying the power to operate a steam turbine. Also, the mercury turbine is gradually being introduced because of its efficiency. And the gas turbine has received wide acclaim recently—not only as setting world speed records for aircraft—but as stationary power plants.

Most people, when they think of nuclear—or atomic—energy, visualize it as a vast potential source of industrial power—and such it may ultimately prove to be.

But first, we must realize that this energy will appear as heat in what is known as "the pile"—or nuclear reactor. Our scientists and engineers see no way of converting directly to electricity the energy of the fissioning atom. So to use this energy in quantity, we must get the heat out of the pile. One way of doing this would be to pump a liquid or gas through the pile and use the heat energy picked up by the liquid to generate steam in the boiler. This steam could then be used to drive a steam turbine-generator to produce electricity. In other words, the atomic pile and some auxiliary equipment would merely replace the fuel-fired steam boiler, and from that point on the atomic power plant will be the same as the one using coal, oil, or gas as fuel. Consequently, the first cost of an atomic power plant will probably be considerably higher than that of a fuel-fired plant under normal conditions. As to operating cost, it is entirely possible that in the years to come the cost of nuclear fuel will be competitive with that of coal or oil. Today we cannot give any reliable estimate of its cost, for there are too many factors which we do not have knowledge of, nor the experience to evaluate properly.

America's first gas turbine, electric-powered locomotive was developed by G.E. and American Locomotive.

The Mercury Turbine

Recently, there has been a renewed interest in mercury turbine application. In operation, liquid mercury is vaporized by heat from a boiler furnace and the vapor is used to drive a mercury-turbine. After the mercury vapor has passed through this turbine, it is piped into a condenser-boiler where it gives off enough additional heat to turn water to steam. This steam is used to drive a regular steam turbine. The new 40,000-kilowatt Schiller Station of the Public Service Company of New Hampshire is using General Electric mercury vapor and steam turbines. This station

is expected to produce more electricity with a given amount of fuel than any generating equipment of comparable size yet built.

The Gas Turbine

In the last nine years, great emphasis has been placed on the gas turbine as a source of power. In October of 1942, just a year after General Electric had contracted to design and develop an aircraft gas turbine for the Army Air Forces, the P-59 Bell Airacomet—our first jet-propelled plane—was ready for flight. Late in 1949, an Army fighter plane, the North American F-86, set an official world speed record of 670.98 miles per hour. In its sleek fuselage was the powerful G-E aircraft gas turbine—commonly known as the "jet engine."

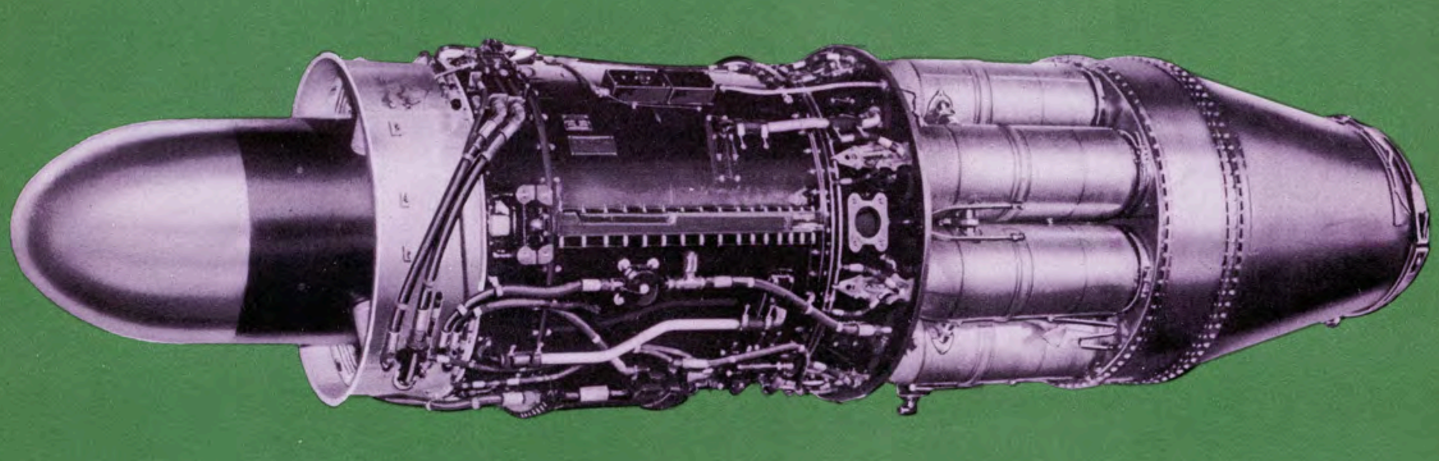
The principle of the aircraft gas turbine is about as simple as that of the steam turbine. Intake air is drawn through a compressor where it is squeezed into the combustion chamber to mix with a spray of fuel. This mixture is ignited, and the resulting blast—or jet—of hot, expanding gases moves into the buckets of a turbine wheel and out through the exhaust nozzle at velocities as high as 2200 feet per second—or twice the normal speed of sound! The reaction to this jet propels the plane forward. But why the turbine wheel? That is used to drive the compressor. The turbine, mounted on the same shaft as the compressor, rotates when the hot gases strike against the buckets. The compressor, being on a direct shaft, also rotates. In the case of another General Electric development, the prop-jet engine, the turbine spins not only the compressor, but also a propeller for conventional flight.

Here, it should be pointed out that there is a major distinction between the aircraft gas turbine and the land applications of the gas turbine. On land, the gas turbine is used, not to propel by reaction or directly operate a propeller, but to spin a generator rotor to produce electricity. This is demonstrated very well by the first gas turbine, electric-powered locomotive in the United States, built by General Electric and the American Locomotive Company. Now in regular service with the Union Pacific, the 500,000 pound "Big Blow"—as it is tenderly referred to—is as powerful as a diesel-electric or steam locomotive twice as long, yet it is only half the weight.

The startling part about the gas turbine is its most recent application—the gas turbine power plant. Economical to operate, it can reach peak load capacity from a cold start in about five minutes to meet extra output demands. To date, the performance record of the first commercial gas turbine power plant in the United States has exceeded expectations. Located at the Arthur F. Huey Station of the Oklahoma Gas & Electric Company, this single unit is rated at 3500 kilowatts. In addition, the turbine's waste exhaust is used to boost the output of the station's existing power plant by 3000 kilowatts—enough to light 30,000 100-watt electric lamps.

This new power source weighs about 85,000 pounds, is less than 50 feet long and nine feet wide. It is pint-sized when compared with a steam turbine power plant of equal capacity. The building necessary to house the gas turbine power plant is only half the size of that required for a steam turbine power plant of similar rating. The gas turbine power plant is fired by a low-grade fuel oil or natural gas.

We may draw this conclusion: the turbine—steam, mercury or gas—will be with us for a good many years to come. Because of this wonderful prime mover, electricity has come to be our most indispensable servant, giving all of us comfort and convenience at a cost that can be measured in pennies. And our General Electric engineers, scientists and manufacturing experts will continue to build even greater and better turbines—to spin the generators that will bring to more people everywhere the convenience, economy, and health— of electrical living.



Powerful General Electric jet engines like the one pictured above are used in many of the latest American military aircraft.

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